Detection of Passive Integrated Transponder (PIT) Tags on Piscivorous Avian Colonies in the Columbia River Basin, 2008

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EXECUTIVE SUMMARY

In 2008, the National Marine Fisheries Service, in collaboration with Oregon State University and Real Time Research, Inc., recovered passive integrated transponder (PIT) tags from piscivorous bird colonies in the Columbia River basin (CRB). The PIT tags had been implanted in juvenile Pacific salmon *Oncorhynchus* spp. for studies of survival and migration behavior. Over 114,000 PIT-tag codes with no previous history of detection on an avian colony were recovered during 2008. Of this total, over 87,000 originated from fish released for migration in 2008. Based on these detections, we estimated that avian predators consumed a minimum of 3.7% of the 2.5 million PIT-tagged salmonids released into the CRB for migration during 2008. Nearly 90% of fish were consumed by either Caspian terns *Hydroprogne caspia* or Double-crested cormorants *Phalacrocorax auritas*. After adjusting for detection efficiencies on the nesting colonies, we estimated that 4.9% of PIT-tagged juvenile salmonids released for migration during 2008 were consumed by these birds.

Primary PIT-tag recovery locations in 2008, as in previous years, were the tern and cormorant colonies located on East Sand Island in the Columbia River estuary, where 71% of all PIT-tags from avian colonies were recovered. Other important recovery locations were tern and gull colonies on Crescent Island and a cormorant colony on Foundation Island. Both of these islands are located in the reservoir upstream from McNary Dam, and PIT tags recovered from these islands accounted for approximately 21% of all recoveries. Sampling at other secondary colonies in the CRB yielded an additional 8% of PIT tag codes collected.

As in previous years, PIT-tagged juvenile steelhead were generally among the most vulnerable to avian predation, regardless of colony location. For example, over 13% of PIT-tagged steelhead that were detected passing Bonneville Dam in 2008 were subsequently detected on East Sand Island. In comparison, approximately 5% of Chinook, coho, and sockeye salmon detected passing Bonneville Dam in 2008 were subsequently detected on East Sand Island. The most vulnerable salmonid ESU in the Columbia River basin in 2008 was lower Columbia River subyearling Chinook salmon. After adjusting for detection efficiencies, we estimated that predation rates on lower Columbia River hatchery subyearling Chinook salmon by terns and cormorants nesting on East Sand Island were over 44%. This predation rate was not only the highest estimated for any salmonid ESU during 2008, but also the highest estimated to date for any PIT-tagged salmonid ESU. Of the subyearling Chinook salmon consumed by avian predators on East Sand Island, approximately 80% were recovered on the Double-crested cormorant colony.

Colony-specific predation rates, which are minimal predation rates adjusted for detection efficiency, showed that the largest proportion of avian predation in the Columbia River Basin occurred on the cormorant and tern colonies on East Sand Island. Analysis of predation by river reach showed that for PIT-tagged juvenile steelhead, estimated rates of avian predation were 16% in the Columbia estuary, 1.0% in the Columbia River Gorge at Miller Rocks Island, and 5.2% on avian colonies near the Snake and Columbia River confluence. By comparison, for PIT-tagged yearling Chinook salmon, estimated rates of predation by river reach were 2.5% in the Columbia River estuary, 0.3% in the Columbia River Gorge at Miller Rocks Island, and 1.5% on avian colonies near the confluence of the Snake and Columbia Rivers.

Predation rates of fish transported and released downstream from Bonneville Dam were less than, but not significantly different from those of non-transported fish. Predation rates of transported fish consumed by birds nesting on East Sand Island were 4.3% for yearling Chinook salmon, 7.4% for subyearling Chinook salmon, 4.3% for Chinook salmon of unknown origin, 16.6% for steelhead, and 3.5% for sockeye salmon.

We included analyses of the relative vulnerability of PIT-tagged fish vs. those implanted with both PIT and acoustic tags (both implanted during surgical procedure). Daily predation rates by birds nesting on East Sand Island of PIT-tagged yearling and subyearling Chinook salmon and steelhead detected passing Bonneville Dam were compared to daily predation rates of double-tagged fish released at or detected passing Bonneville Dam. Transported fish were not included in this analysis. We found that predation rates of double-tagged yearling and subyearling Chinook salmon were significantly greater than those of fish with only a PIT tag ($P = 0.016$ for yearlings and $P < 0.001$ for subyearlings). Differences in predation rates among double-tagged and PIT-tag only steelhead were not significant ($P = 0.194$). Differences in weekly predation rates of double-tagged and PIT-tagged fish by birds nesting on upriver breeding colonies were not significant, but these comparisons had less statistical power due to small sample sizes.

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INTRODUCTION

Since 1987, juvenile Pacific salmonids *Oncorhynchus* spp. have been tagged with passive integrated transponder (PIT) tags to evaluate measures implemented to improve their survival through the Federal Columbia River Power System (FCRPS). PIT-tagging has also aided in identifying causes of decline in salmonids at different life history stages (NMFS 2000). The annual number of PIT-tagged juvenile salmonids released in the Columbia River basin (CRB) varies, but has increased from less than 50,000 in 1987 to over 2,000,000 by 2003 (PSMFC 1996–). At the time of tagging, individual tag codes and other information, such as species type and origin, are recorded in a regional database, the PIT Tag Information System (PTAGIS) for the Columbia River Basin (PSMFC 1996–). After entry, codes in PTAGIS can be matched with subsequent detection records at dams and other interrogation sites. These data can then be used to establish the migration history and often the ultimate fate of individual fish.

Since the mid-1960s, colonies of Caspian tern *Hydroprogne caspia* have shifted northward from California, and by the 1980s, had begun to concentrate on small islands in the Columbia River estuary (Gill and Mewladt 1983). By 2001, over 12,000 terns were reported along the north Pacific coast (USACE 2001). Colonies of Double-crested cormorants *Phalacrocorax auritas* have also expanded rapidly in the Columbia River estuary, from initial sightings in the 1980s (Carter et al. 1995) to approximately 14,000 breeding pairs in 2007 (BRNW 2007). Both the tern and cormorant colonies are considered to be the largest of their respective species in North America.

Large-scale efforts to detect PIT tags on avian predator colonies in the CRB began in 1998 (Ryan et al. 2001). The goal of these efforts was to obtain PIT-tag data with which to compare vulnerability to predation of different salmonid species, runs or rear types, and areas of origin (Collis et al. 2001; Ryan et al. 2003). High levels of annual salmonid consumption related to these large breeding colonies of avian piscivores were indicated.

These initial findings prompted management agencies to relocate the estuarine Caspian tern colony from Rice Island (freshwater reach) downstream to East Sand Island (brackish water reach). The relocation was intended to mitigate predation on salmonids by moving terns closer to food sources of non-salmonid, marine forage fishes (USACE 2001). PIT-tag detection efforts on these and other colonies throughout the CRB continued to focus on evaluating the relative vulnerability of salmonids to avian predation. Presently, these efforts primarily target the larger avian colonies responsible for the majority of predation on juvenile salmonids. This approach was intended to develop data for better evaluation of management alternatives for avian colonies.

We used modified PIT-tag detection equipment (Prentice et al. 1990a,b) to recover juvenile salmonid tags from the nesting colonies in 2008. In previous years, biologists from Oregon State University (OSU) and Real Time Research, Inc. (RTR) assisted with PIT-tag recovery efforts of the National Marine Fisheries (NMFS). Beginning in 2007, we divided recovery efforts on colonies to among research groups stationed within different geographic regions of the CRB. We then pooled detection information for our respective analyses. In this report, we summarize the PIT-tag recovery, methodology, and general vulnerabilities of juvenile salmonids to avian predators in 2008. Data obtained during this study contributed to additional analyses of the broader aspects of avian behavior, population dynamics, smolt consumption, and species-specific vulnerabilities of juvenile salmonids to avian predation. These data have also contributed to analyses of avian predation, including the relative vulnerability of juvenile salmonids to predation, obtained by expanded PIT-tag recoveries.

METHODS

Study Sites

Our study sites consisted of 15 distinct avian breeding colonies on 13 islands (Table 1). All PIT-tag sampling occurred during summer and fall, after the terminus of the breeding season and birds had vacated the nesting colonies. Locations of avian colonies ranged from East Sand Island, at river kilometer (rkm) 8 in the Columbia River estuary to Banks Lake a 43-km-long irrigation reservoir located south of the Columbia River near rkm 959 (Figure 1). PIT-tag recovery efforts were concentrated on the largest avian predator colonies located on islands in the Columbia River estuary (Figure 2) and on islands in the reservoir of McNary Dam near the confluence of the Columbia and Snake Rivers.

Table 1. Location of avian breeding colonies and distance from Columbia River mouth.

River Reach and Island	rkm
Columbia River estuary	
East Sand Island	8
Rice Island	34
The Dalles Dam Reservoir/Lake Celilo	
Miller Rocks Island	331
John Day Dam Reservoir	
Rock Island	441
McNary Dam Reservoir/Lake Wallula	
Crescent Island	510
Badger Island	512
Foundation Island	518
Island 20	545
Island 18	553
Upper Columbia River	
Goose Island	641
Beverly Islands	666
Ice Harbor Dam tailrace	
Goose Island	536
Potholes Reservoir	
Goose Island	665
Banks Lake	959

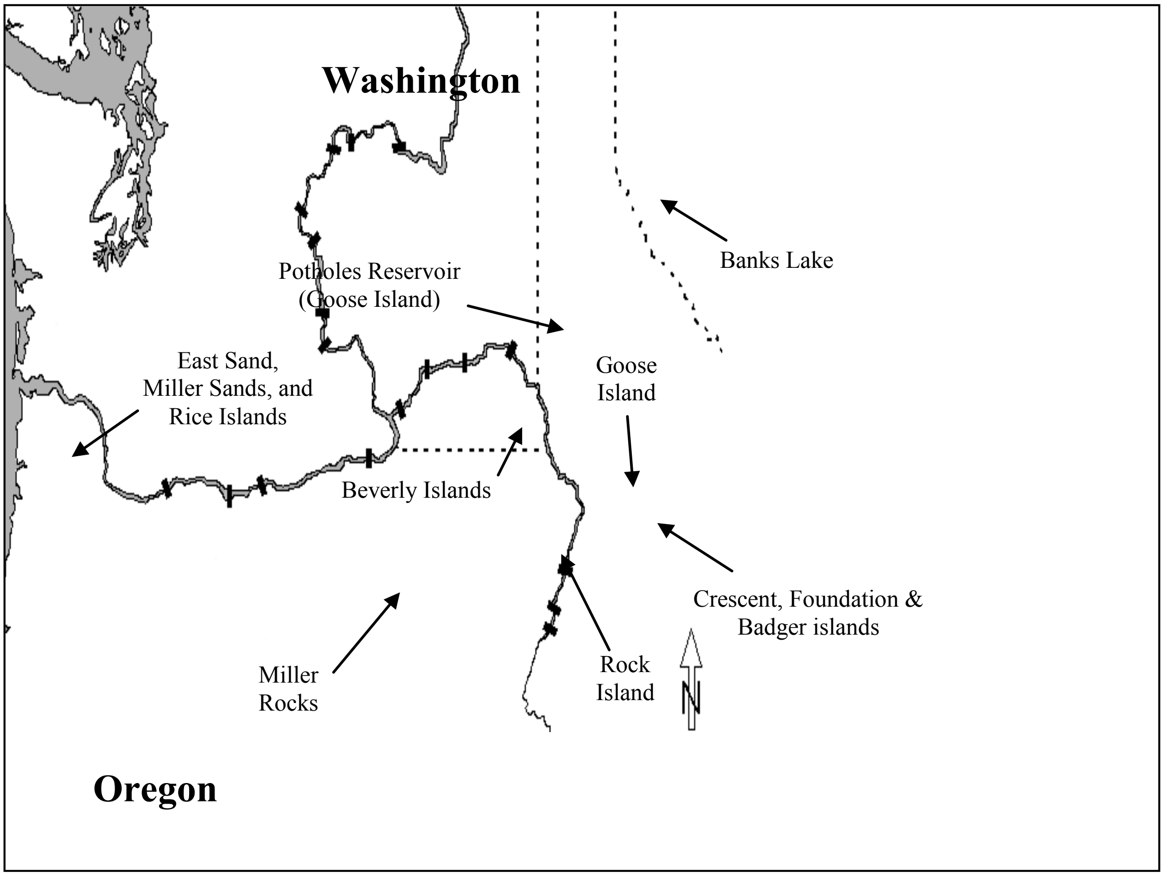

Figure 1. Location of avian predator nesting colonies and post-nesting season PIT tag collection efforts, 2008.

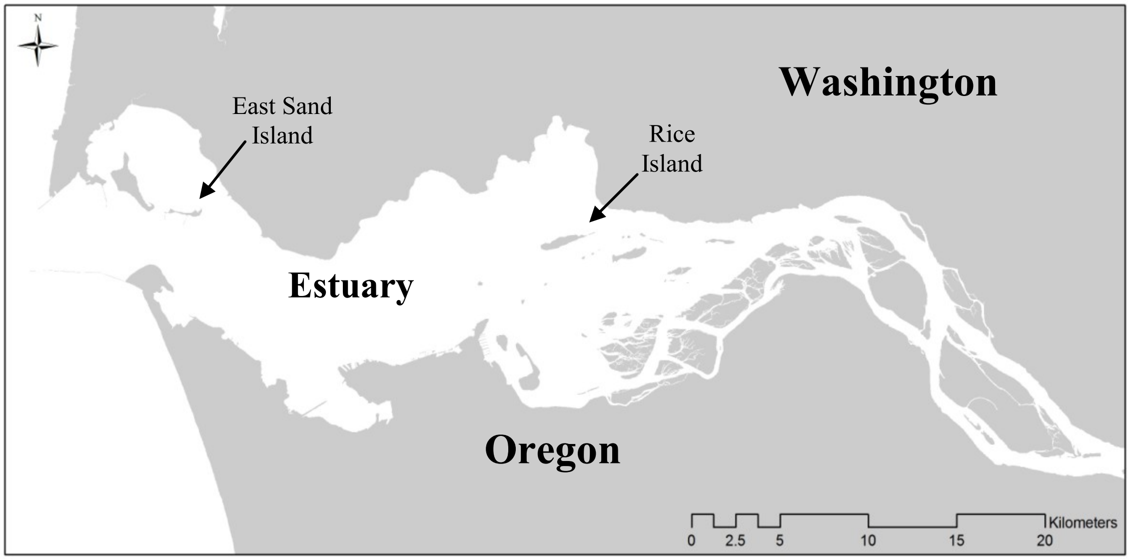

Figure 2. PIT tag recovery efforts in the Columbia River estuary were conducted on East Sand Island (Caspian tern and Double-crested cormorant colonies), 2008. The tern colony on Rice Island was relocated to East Sand Island in 1999-2000.

PIT-Tag Recovery

In 2008, PIT-tag recovery efforts were conducted by NMFS, OSU, and RTR, research staff at separate locations throughout the CRB. Tags from East Sand Island were recovered by NMFS staff based at the Point Adams Research Station, located near the Columbia River estuary. We also provided tractor-towed, flat-plate antenna systems to assist in recovery of tags on Crescent Island tern and gull colonies. Tags from avian colonies in the mid- and upper Columbia River were recovered by OSU and RTR. These agencies focused primarily on Crescent and Foundation Islands, but also recovered tags from other colonies in that region. Recovery data from previous years indicated that a large proportion of PIT tags would be located on Crescent, East Sand, and Foundation Islands (Ryan et al. 2003, 2006, 2007), and that several other colonies would have substantial numbers of PIT tags (Ryan et al. 2001, 2002). These secondary colonies were located on islands in the reservoirs of The Dalles and John Day Dams and on islands upstream from Priest Rapids Dam and in the Potholes Reservoir.

We used hand-held transceivers and flat-plate antenna systems for PIT-tag detection, as described by Ryan et al. (2001). Flat-plate antennas were used primarily on Crescent and East Sand Island tern colonies, where potential for tag code collision was greatest due to higher densities of PIT tags. Collision of tag codes occurs when two or more PIT tags are present in the detection field simultaneously, resulting in interference between tag-code signals so that neither tag code is correctly read by the transceiver (Brännäs et al. 1994). Tern colonies are generally located on more level, unobstructed terrain, which allowed NMFS to operate a tractor to tow the flat-plate antennas. Hand-held antennas were used as an alternative technique where rugged, obstructed terrain limited use of flat-plate antennas. We attempted to maximize detections by using the flat-plate antennas to perform multiple passes over the colonies in different directions.

Detection Efficiency

As in previous years, we collaborated with OSU and RTR to distribute known numbers of PIT tags, hereafter referred to as control tags, on avian colonies at various intervals throughout the breeding season. Colony-specific detection efficiencies were calculated by dividing the number of control tags electronically recovered (detected) by the total number of control tags planted on the colony. Detection efficiency was calculated in this manner for all avian colonies except the cormorant colony on East Sand Island. Cormorants on this island nested over a large area with a diversity of substrates, where control tags could not be systematically dispersed.

Dispersion of control tags on the East Sand Island cormorant colony was likely to produce biased estimates of detection efficiency. Potential bias would arise from the unrepresentative distribution of control tags over each substrate type and from differences in proportions of the population using a particular substrate. We attempted to correct for this bias by calculating the number of PIT tags deposited by birds nesting on experimental nesting platforms with a standard dimension and a known number of nesting cormorants. These estimates relied on the assumptions that nesting on the experimental platforms made no difference in the likelihood of cormorants to either consume PIT-tagged salmonids or deposit PIT tags on the nesting area. The number of PIT tags consumed by cormorants nesting on experimental platforms was then extrapolated to produce a detection efficiency estimate for the entire population of cormorants nesting on East Sand Island.

Colony-Specific Predation

In addition to estimates of basin-wide avian predation rates, we also estimated predation rates for PIT-tagged salmonids known to be migrating within three specific reaches of the Columbia River (McNary Dam reservoir, The Dalles Dam reservoir, and the Columbia River estuary). Nearly 80% of all colony detections from PIT-tagged salmon were made on avian colonies within these river reaches. These colonies include Caspian terns and Double-crested cormorants nesting on East Sand Island, gulls nesting on Miller Rocks Island, and Caspian terns and Double-crested cormorants nesting on Crescent and Foundation Island, respectively. Detections of PIT tags at the nearest location upstream from these colonies were used as an index of PIT-tagged fish available to avian predators. A minimum of 100 detections was required to calculate weekly predation rates. PIT-tagged fish detected at Bonneville Dam were used as an index of fish available to avian predators in the Columbia River estuary. Likewise, PIT-tagged fish detected at John Day and McNary Dams were used as an index of fish available to avian predators nesting on Miller Rocks Island in the Columbia River Gorge. To provide and index of PIT-tagged fish available to avian predators in McNary Dam reservoir, we used two indices: fish detected at Ice Harbor or Lower Monumental Dam provided an index of fish originating in the Snake River, and PIT-tagged fish released from Rock Island Dam (rkm 730) provided an index of fish originating in the upper Columbia River.

We also evaluated the effects of migration history by comparing avian predation rates on groups of transported and inriver migrating fish in the Columbia River estuary. Avian predation rates by terns and cormorants nesting on East Sand Island of fish released from transport barges downstream from Bonneville Dam at Skamania Landing (rkm 224) were compared to those of inriver migrating fish detected at Bonneville Dam during the same week. A minimum of 100 detections was required to calculate weekly predation rates. All species and run-types presented are as listed in PTAGIS (2009).

PIT-Tagging of Lower Columbia River Stocks

During 2008, we continued PIT-tagging subyearling Chinook salmon from the lower Columbia River (LCR) to evaluate avian predation on this evolutionary significant unit (ESU). The LCR Chinook salmon has a distinct life history type (Narum et al. 2004) and is represented by few PIT-tagged individuals. Using techniques described in Ryan et al. (2006), we PIT tagged over 12,000 subyearling fall Chinook salmon in spring and early summer at four hatcheries located on rivers flowing into the LCR. Tagging was conducted at the Big Creek (rkm 49), Elochoman (rkm 79), Kalama Falls (rkm 135), and Warrenton High School Hatcheries (rkm 14). These four release groups of fish were used to examine whether predation rates of subyearling fall Chinook salmon released near the estuary were similar to those of stocks released further upstream. We compared predation rates of PIT-tagged subyearlings released into the LCR to those of PIT-tagged subyearlings interrogated at Bonneville Dam during the same week. Tags form transported fish were excluded from the analysis to avoid potential bias related to migration history.

Comparative Predation of PIT-Tagged vs. PIT and Acoustic-Tagged Fish

In addition to our annual analyses of avian predation, we included a comparative analyses of PIT-tagged fish vs. those implanted with both a PIT and acoustic tag during a single surgical procedure (hereafter referred to as double-tagged fish). In 2008, there were 36,436 double-tagged fish released into the Columbia River basin for various studies using a variety of tag-types and tagging protocols, but all involved surgical implantation of these tags (PTAGIS, 2008). Due to the necessity of controlling for release location and migration timing as factors biasing relative vulnerability to avian predation, we summarized releases from PTAGIS of non-transported PIT-tagged and double-tagged fish released from Lower Granite Dam (rkm 635) and those detected at or released from Bonneville Dam (rkm 234).

We analyzed relative vulnerability of double-tagged and PIT-tagged fish to predation by Caspian terns and double-crested cormorants within two regions of the Columbia River basin, the estuary and the mid-Columbia River. Estuary colonies included birds nesting on East Sand Island, whereas mid-Columbia colonies included birds nesting on Crescent and Foundation Island. For comparison of predation rates in the estuary, we combined numbers fish either detected passing at or released at Bonneville Dam on the same dates. Groups of fish detected or released at Bonneville Dam were combined for both the double-tagged and PIT-tagged fish treatments. These combined groups provided an index of vulnerability to avian predation in the estuary based on tag type. For comparison of predation rates in the mid-Columbia River, we formed similar index groups of fish detected or released at Lower Granite Dam, except that weekly rather than daily totals of PIT-tagged and double-tagged fish were used. Weekly numbers were used for fish detected or released at Lower Granite Dam because fewer fish were released from this location.

We compared mean seasonal predation rates calculated for double-tagged and PIT-tagged fish released upstream from the estuary with tags found on Mid-Columbia avian colonies. Only fish consumed by terns or cormorants nesting at these nesting locations were included in the analysis because sufficiently large numbers of double-tagged and PIT-tagged fish were consumed over multiple weeks to calculate reliable predation rates. We assumed equal probability that PIT tags from either group would be deposited on avian colonies and an equal probability of detection.

RESULTS

PIT-Tag Recovery

Using physical and electronic recovery techniques, we collected over 114,000 PIT-tag codes with no previous detection history on avian breeding colonies during 2008 (Appendix Table 1). Over 88,000 of these tag codes were from fish migrating during 2008 (PTAGIS; Table 2). This total represented 3.7% of all fish released in the CRB for migration during 2008 and was a minimum estimate of predation by colonial nesting avian predators. We expanded this observed total based on mean detection efficiencies of control tags planted on colonies throughout the nesting season. Based on the respective mean detection efficiencies at each colony, we estimated that approximately 117,000 PIT-tagged fish, or about 4.9% of those released for migration during 2008, were consumed by avian predators in the CRB.

Table 2. Number of PIT tag codes recovered on avian predator breeding colonies in 2008 that were not detected in previous years. The percentage of the total annual recovery is listed for each island and colony.

Recovery site	American White Pelican	Caspian tern	Double-crested cormorant	Gull species	Mixed species	Total recovered	Percent recovered
Beverly Islands					190	190	0.2
Badger Island	1,769					1,769	1.5
Banks Lake		60				60	0.1
Crescent Island		8,181		1,936	1,300	11,417	10.0
East Sand Island		45,513	31,595	4		77,112	67.4
Foundation Island			10,243			10,243	9.0
Island 20				718		718	0.6
Goose Island (Ice Harbor tailrace)					10	10	0.0
Miller Rocks Island				6,932	419	7,351	6.4
Potholes		2,326		268		2,594	2.3
Rice Island				47		47	0.0
Rock Island		2,821				2,821	2.5
Goose Island (Wanapum Res.)					402	402	0.4
Total recovered	1,769	58,901	41,838	9,905	2,321	114,374	
Percent recovered	1.5	51.5	36.6	8.7	2.0		

The greatest effect of avian predators in any river reach occurred in the Columbia River estuary where 3.4% of the PIT-tagged juvenile salmonids released for migration during 2008 were consumed (Table 3). Detection of PIT-tags from colonies on islands in the reservoir of McNary Dam and Miller Rocks Island accounted for another 1.1 and 0.2%, respectively, of recoveries from fish released to migrate during 2008. These proportions were considerable, given the relatively small size of these avian colonies compared to those in the estuary. Recoveries of PIT-tags from juvenile salmon consumed by birds nesting on all other islands in the CRB combined accounted for 0.2% of the total for fish migrating during 2008.

Table 3. Number of PIT tags listed in PTAGIS as fish migrating during 2008 that were consumed by avian predators in 2008 and the percent of those recovered by island and colony.

Recovery site	American White Pelican	Caspian tern	Double-crested cormorant	Gull species	Mixed species	Total recovered	Percent recovered
Beverly Islands					2	2	0.0
Badger Island	1,425					1,425	1.6
Banks Lake		51				51	0.1
Crescent Island		7,214		1,444	525	9,183	10.4
East Sand Island		41,984	21,228	2		63,214	71.7
Foundation Island			7,259			7,259	8.2
Island 20				139		139	0.2
Goose Island (Ice Harbor Res.)					3	3	0.0
Miller Rocks Island				3,339	108	3,447	3.9
Potholes		1,988		65		2,053	2.3
Rice Island				16		16	0.0
Rock Island		1,267				1,267	1.4
Goose Island (Wanapum Res.)					53	53	0.1
Total recovered	1,425	52,504	28,487	5,005	691	88,112	
Percent recovered	1.6	59.6	32.3	5.7	0.8		

Detection Efficiency

Mean detection efficiency ranged from 52 to 93% in evaluations using control tags planted on bird colonies by OSU/RTR at primary detection locations on East Sand Island (Appendix Table 1) and upriver detection locations (Appendix Table 2). Similar detection efficiencies were measured on these colonies during 2007 (Sebring et al. 2009). We found a significant temporal relationship of the percent of control tags detected based on date of release for the Caspian tern colony on Crescent Island (Appendix Figure 1) and developed a regression model to estimate temporal change in detection efficiency for this colony during 2008 ($R^2 = 0.9$).

We adjusted mean detection efficiency estimates for the East Sand Island Double-crested cormorant colony by combining control tag data and on-colony bird observations from experimental nesting plots. Mean detection efficiency on the East Sand Island cormorant colony was 82% for all habitat types (colony-wide, rip-rap, and experimental nest plot). A total of 610 cormorants were observed nesting on experimental nest plots. Mean detection efficiency for experimental nest plots was 87%; thus we estimated that cormorants using nest platforms consumed 1,043 PIT tags from fish released for migration during 2008. Using these data, we estimated per capita consumption of 1.71 PIT-tagged fish per cormorant. Estimates of the total number of adult cormorants nesting on East Sand Island during 2008 (n = 21,900) were gathered from the annual population census by OSU and RTR. Based on per capita consumption of PIT-tagged fish by cormorants, and on the adult nesting population, we estimated a total of 37,449 PIT tags were consumed from fish migrating during 2008. The detection efficiency estimate adjusted for the entire cormorant colony was 57%.

Colony-Specific Predation

We measured predation effects of avian colonies in Lake Wallula (McNary Dam reservoir), the Columbia River Gorge, and the Columbia River estuary using the nearest upstream detection site as an index of fish vulnerable to avian predation. For all fish species released from Rock Island Dam, the predation rate by cormorants nesting on Foundation Island was less than 0.5% (Table 4). For these same fish, predation rates by Caspian terns nesting on Crescent Island were greater, although they did not exceed 3%. Predation rates of Chinook salmon and steelhead detected at the lower Snake River dams were generally greater than those of fish originating from the upper Columbia River (Table 5).

Table 4. Number of salmonids collected and PIT-tagged at Rock Island Dam in 2008 and colony-specific predation rates for Crescent Island terns and Foundation Island cormorants. Numbers of PIT tags recovered are shown with estimated predation rates adjusted for detection efficiencies of 62% for tern and 74% for cormorant colonies.

Salmonid species/ Run type		Crescent Island terns			Foundation Island cormorants		
		Hatchery	Wild	Unknown	Hatchery	Wild	Unknown
Unknown Chinook salmon	Released	4,520			4,520		
	Recovered	8			3		
	Est. Predation (%)	**0.29**			**0.09**		
Steelhead	Released	4,192	1,860	1,730	4,192	1,860	1,730
	Recovered	60	18	25	5	1	1
	Est. Predation (%)	**2.32**	**1.57**	**2.34**	**0.16**	**0.07**	**0.08**

Table 5. Number of PIT-tagged salmonids detected at Ice Harbor Dam or Lower Monumental Dam in 2008 and colony-specific predation rates for Crescent Island terns and Foundation Island cormorants. Numbers of PIT tags recovered are shown with estimated predation rates adjusted for detection efficiencies 62% for tern and 74% for cormorant colonies.

Salmonid species/ run type		Crescent Island terns			Foundation Island cormorants		
		Hatchery	Wild	Unknown	Hatchery	Wild	Unknown
Spr/Sum Chinook salmon	Released	19,598	3,743		19,598	3,743	
	Consumed	66	7		189	11	
	Est. Predation (%)	**0.54**	**0.30**		**1.30**	**0.40**	
Fall Chinook salmon	Released	21,179		867	21,179		867
	Consumed	48		12	64		7
	Est. Predation (%)	**0.37**		**2.24**	**0.41**		**1.09**
Unknown Chinook salmon	Released	12,648	2,230		12,648	2,230	
	Consumed	32	7		83	8	
	Est. Predation (%)	**0.41**	**0.51**		**0.88**	**0.48**	
Steelhead	Released	13,882	4,599	540	13,882	4,599	540
	Consumed	155	71	20	287	42	8
	Est. Predation (%)	**1.81**	**2.50**	**5.99**	**2.78**	**1.23**	**1.99**
Sockeye salmon	Released	174			174		
	Consumed	1			1		
	Est. Predation (%)	**0.93**			**0.77**		

With the exception of steelhead, detections from gulls nesting on Miller Rocks Island made up less than 1% of the recoveries from any salmonid species or rear type, despite the proximity of this island to The Dalles and John Day Dams (Table 6). Predation rates of fish detected at Bonneville Dam and consumed by East Sand Island cormorants were greatest for steelhead and Chinook salmon (Table 7). East Sand Island terns consumed an estimated 9.9% of steelhead detected at Bonneville Dam, the greatest colony-specific predation rate measured in 2008. For steelhead known to be vulnerable to avian predation in the Columbia estuary, the combined predation rate from cormorants and terns nesting on East Sand Island exceeded 15%.

Table 6. Number of PIT-tagged salmonids detected at McNary and/or John Day Dam in 2008 and the predation rates of gulls nesting on Miller Rocks Island. Included are numbers of PIT tags recovered and estimated predation rates adjusted for a detection efficiency of 82%.

		Miller Rocks Island gulls		
Salmonid species/run type		Hatchery	Wild	Unknown
Spring/Summer Chinook salmon	Released	51,408	11,859	1,046
	Recovered	139	17	4
	Est. Predation (%)	**0.33**	**0.17**	**0.47**
Fall Chinook salmon	Released	1,507	1,444	1,507
	Recovered	164	1	4
	Est. Predation (%)	**0.32**	**0.08**	**0.32**
Unknown Chinook salmon	Released	35,371	4,822	1,034
	Recovered	100	10	4
	Est. Predation (%)	**0.34**	**0.25**	**0.47**
Coho salmon	Released	6,589		
	Recovered	46		
	Est. Predation (%)	**0.85**		
Steelhead	Released	32,872	10,164	1,913
	Recovered	268	74	20
	Est. Predation (%)	**0.99**	**0.89**	**1.27**
Sockeye salmon	Released	763	51,408	777
	Recovered	4	139	3
	Est. Predation (%)	**0.64**	**0.33**	**0.47**

Table 7. Number of PIT-tagged salmonids detected at Bonneville Dam in 2008 and colony-specific predation rates of terns and cormorants on East Sand Island. Included are numbers of PIT tags recovered and estimated predation rates adjusted for detection efficiencies of 92% for tern and 57% for cormorant colonies.

		East Sand Island terns			East Sand Island cormorants		
Species/Run		Hatchery	Wild	Unknown	Hatchery	Wild	Unknown
Spring/Summer Chinook salmon	Released	19,588	3,357	15	19,588	3,357	15
	Recovered	409	27	580	262	28	5
	Est. Predation (%)	**2.25**	**0.86**	**2.78**	**2.35**	**1.46**	**1.51**
Fall Chinook salmon	Released	53,942	327	1,052	53,942	327	1,052
	Recovered	787	3	20	1,810		
	Est. Predation (%)	**1.57**	**0.99**	**2.04**	**5.89**		
Unknown Chinook salmon	Released	12,702	2,745	1,120	12,702	2,745	1,120
	Recovered	268	6	43	156	7	49
	Est. Predation (%)	**2.27**	**0.58**	**1.68**	**2.15**	**1.1**	**3.13**
Coho salmon	Released	2,776			2,776		
	Recovered	99			38		
	Est. Predation (%)	**3.83**			**2.4**		
Steelhead	Released	23,569	4,509	847	23,569	4,509	847
	Recovered	2,189	336	83	976	138	32
	Est. Predation (%)	**9.99**	**8.01**	**10.54**	**7.26**	**5.37**	**6.63**
Sockeye salmon	Released	174	299		174	299	
	Recovered	2	2		3	4	
	Est. Predation (%)	**1.24**	**0.72**		**3.02**	**2.35**	

We evaluated the effect of transportation by comparing cumulative and temporal avian predation rates of inriver migrant fish detected at Bonneville Dam to those of fish released from barges downstream from Bonneville Dam at Skamania Landing (rkm 224). For inriver migrant fall Chinook salmon and steelhead, predation rates by cormorants on East Sand Island were approximately twice that of transported fish of identical species, run, and origin (Table 8). Predation rates by terns on East Sand Island were similar for transported and inriver migrant fish (Table 9).

Table 8. Number of PIT-tagged salmonids released from transport barges at Skamania Landing in 2008 and the percentage of those fish consumed by Double-crested cormorants nesting on East Sand Island. Included are the actual percentages of those tags recovered and estimated percentage of PIT tags deposited based on adjusted detection efficiency (DE).

		East Sand Island Double-crested cormorant colony (detection efficiency = 57%)			
		Number of fish		Predation rate (%)	
Species/Run	Rear type	Consumed	Released	Actual	Estimated
Spring/Summer Chinook salmon	Hatchery	1,120	91,904	1.22	**2.14**
	Wild	54	4,957	1.09	**1.91**
Fall Chinook salmon	Hatchery	1,143	67,800	1.69	**2.96**
Unknown Chinook salmon	Hatchery	310	41,895	0.74	**1.30**
	Unknown	30	3,789	0.79	**1.39**
	Wild	308	22,066	1.40	**2.45**
Steelhead	Hatchery	1,509	96,480	1.56	**2.74**
	Wild	439	27,806	1.58	**2.77**

Table 9. Number of PIT-tagged salmonids released from transport barges at Skamania Landing in 2008 and the percentage of those fish consumed by Caspian terns nesting on East Sand Island. Included are the actual percentages of those tags recovered and estimated percentage of PIT tags deposited based on detection efficiencies (DE).

		East Sand Island Caspian tern colony (detection efficiency = 92%)			
Species/Run	Rear type	Consumed	Released	Actual %	Estimated %
Spring/Summer Chinook salmon	Hatchery	2,607	91,904	2.84	**3.05**
	Wild	43	4,957	0.87	**0.93**
Fall Chinook salmon	Hatchery	649	67,800	0.96	**1.03**
Unknown Chinook salmon	Hatchery	869	41,895	2.07	**2.23**
	Unknown		3,789		
	Wild	344	22,066	1.56	**1.68**
Steelhead	Hatchery	10,035	96,480	10.40	**11.18**
	Wild	1,951	27,806	7.02	**7.54**

Temporal trends in weekly predation rates and proportions of transported to inriver migrating fish consumed by avian predators were related to river flow conditions for some fish species. For spring/summer Chinook salmon, transported and inriver fish were consumed in relatively equal proportions throughout the migration season, but predation rates for both decreased during peak river flow periods (Figure 3). Predation rates of transported and inriver fall Chinook salmon were similar, with the exception of greater predation rates for early-season migrants (Figure 4). Transported and inriver steelhead were relatively equal in their vulnerability to predation and were uniformly vulnerable to avian predation throughout the migration season (Figure 5).

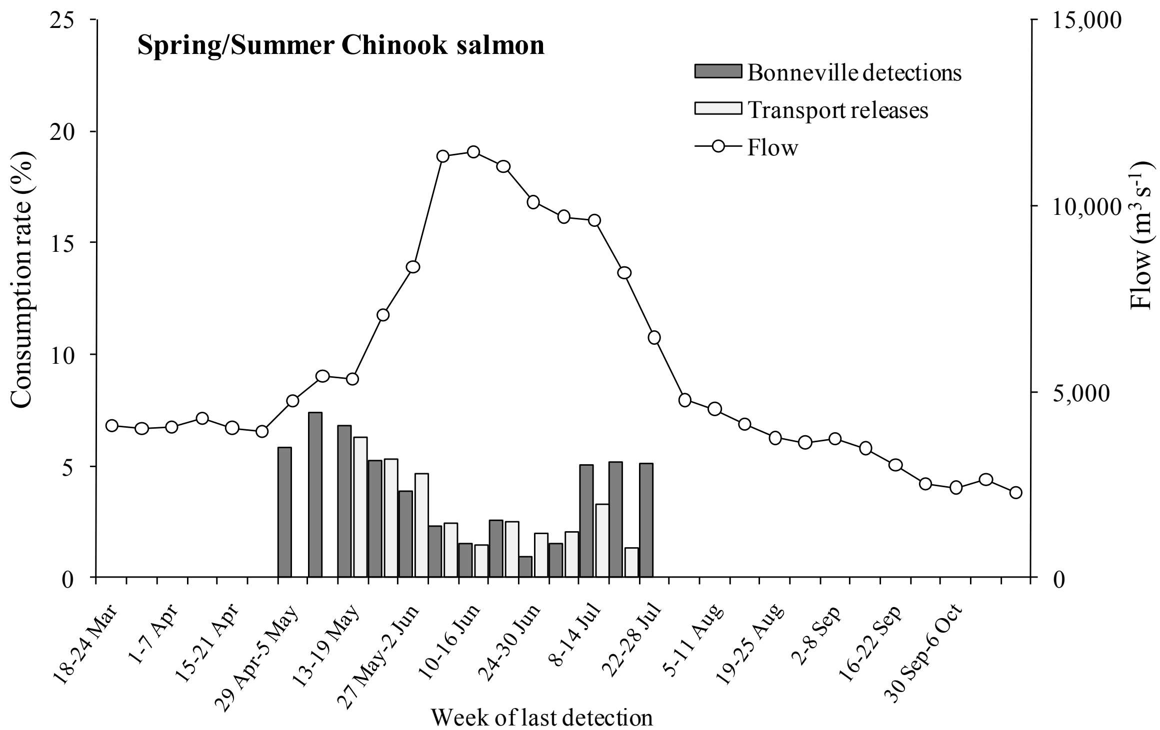

Figure 3. Weekly avian predation rates of spring/summer Chinook salmon previously detected at Bonneville Dam or released from barges at Skamania Landing (rkm 224) during 2008. Average weekly flow at The Dalles Dam is also presented.

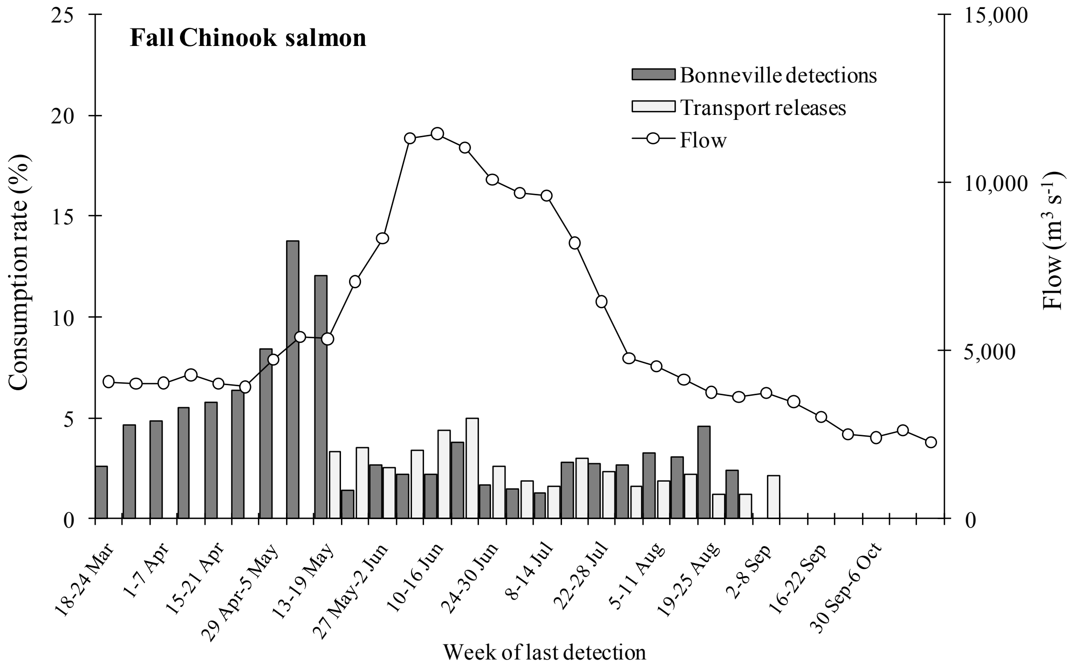

Figure 4. Weekly avian predation rates of fall Chinook salmon previously detected at Bonneville Dam or released from transport barges at Skamania Landing (rkm 224). Average weekly flow at The Dalles Dam is also presented.

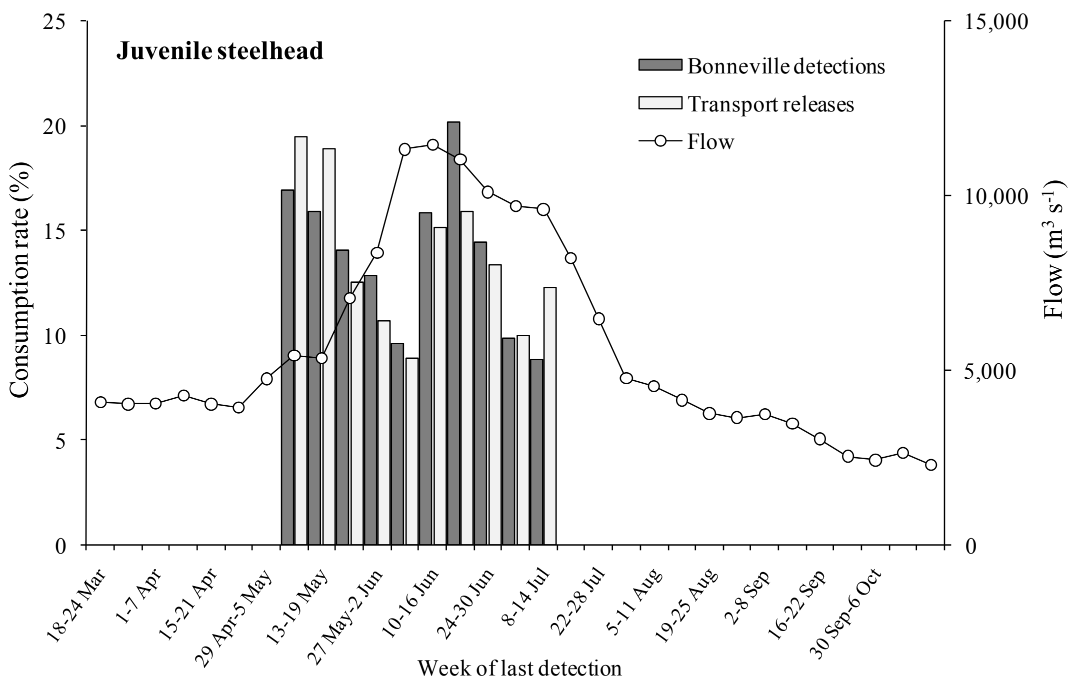

Figure 5. Weekly avian predation rates of steelhead previously detected at Bonneville Dam or released from transport barges at Skamania Landing (rkm 224). Average weekly flow at The Dalles Dam is also presented.

PIT-Tagging of Lower Columbia River Stocks

We PIT-tagged a total of 12,390 subyearling Chinook salmon that were released into the LCR from four hatcheries during mid-May to early July (Table 10). Records obtained from PTAGIS (PSMFC 1996–) showed that a total of 55,321 PIT-tagged subyearling Chinook salmon from various upstream release sites were detected at Bonneville Dam during March-July 2008. Less than 3% of these 55,321 fish were not of hatchery origin. The mean predation rate of avian predators nesting on East Sand Island was 26.9% of fish released into the LCR, a predation rate twice as great as observed for LCR subyearling Chinook salmon during 2007 (Sebring et al. 2009). A mean avian predation rate of 6.4% was observed for fish previously detected at Bonneville Dam.

Table 10. Numbers of PIT-tagged subyearling Chinook salmon released from LCR hatcheries or detected at Bonneville Dam and proportions subsequently consumed by avian piscivores on East Sand Island, 2008.

Release location	Release date (2008)	Distance from Columbia River mouth (km)	Number of fish released	Cormorant (%)	Tern (%)	Total (%)
Big Creek	14 May	49	3,028	20.5	4.8	25.3
Elochoman	6 June	77	3,013	22.9	5.0	27.9
Kalama Falls	7 July	135	3,278	19.8	3.5	23.3
Warrenton HS	13 June	14	3,011	28.2	2.8	31.1
Bonneville Dam	-	234	49,156	3.6	1.5	6.4
Mean LCR fish	-	-	12,390	22.9	4.0	26.9

For all LCR subyearling Chinook salmon release groups in 2008, avian predation rates were greater than 20% (Figure 6). Approximately 85% of PIT-tagged LCR subyearling Chinook salmon with tags detected on avian colonies had been preyed on by Double-crested cormorants. Avian predation rates of subyearling Chinook salmon detected at Bonneville Dam were greatest from March through May (mean 9%) (Figure 7). During this period, the majority of fish migrating were tule stock released from Spring Creek National Fish Hatchery. Predation rates of subyearling Chinook salmon detected at Bonneville Dam were lower (mean 3%) later in the migration season, from June through August. The majority of subyearling Chinook salmon migrating later in the season were upriver bright stock and had been released further upstream in the CRB. In general, we found the majority of subyearling Chinook salmon was consumed by cormorants, and that predation rates were greater for tule than upriver bright stocks, regardless of release location.

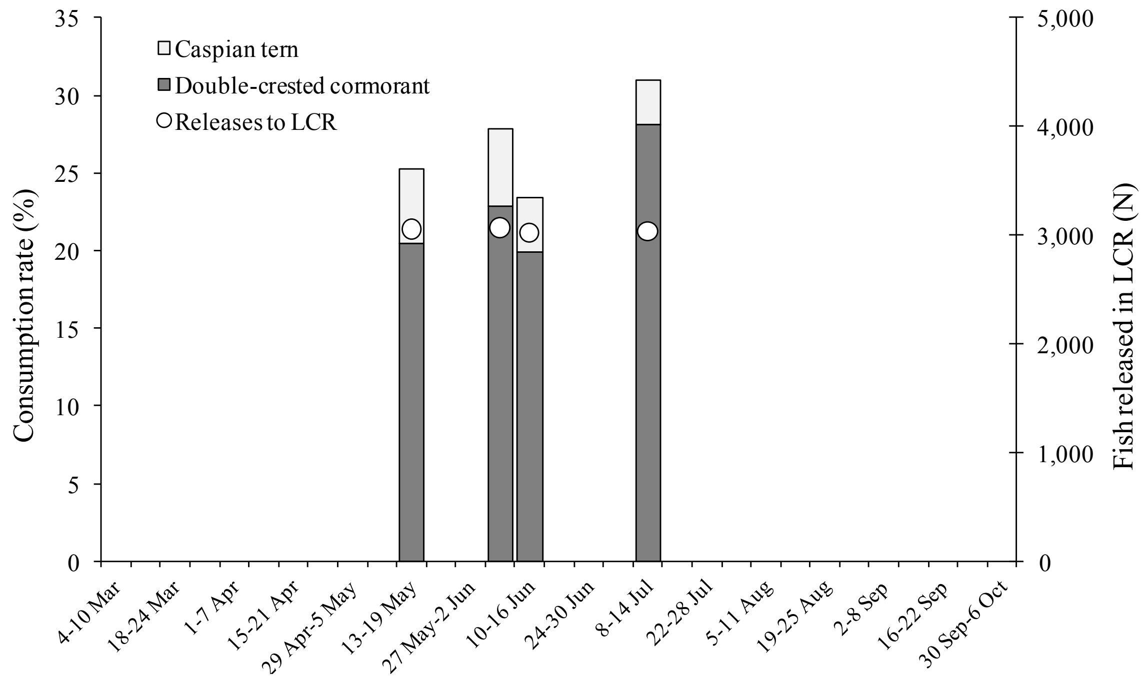

Figure 6. Seasonal predation rates of subyearling Chinook salmon by Caspian terns and Double-crested cormorants by week of release in the Columbia River estuary, 2008. Predation rates were calculated for weeks in which a minimum of 100 fish were detected on avian predator colonies.

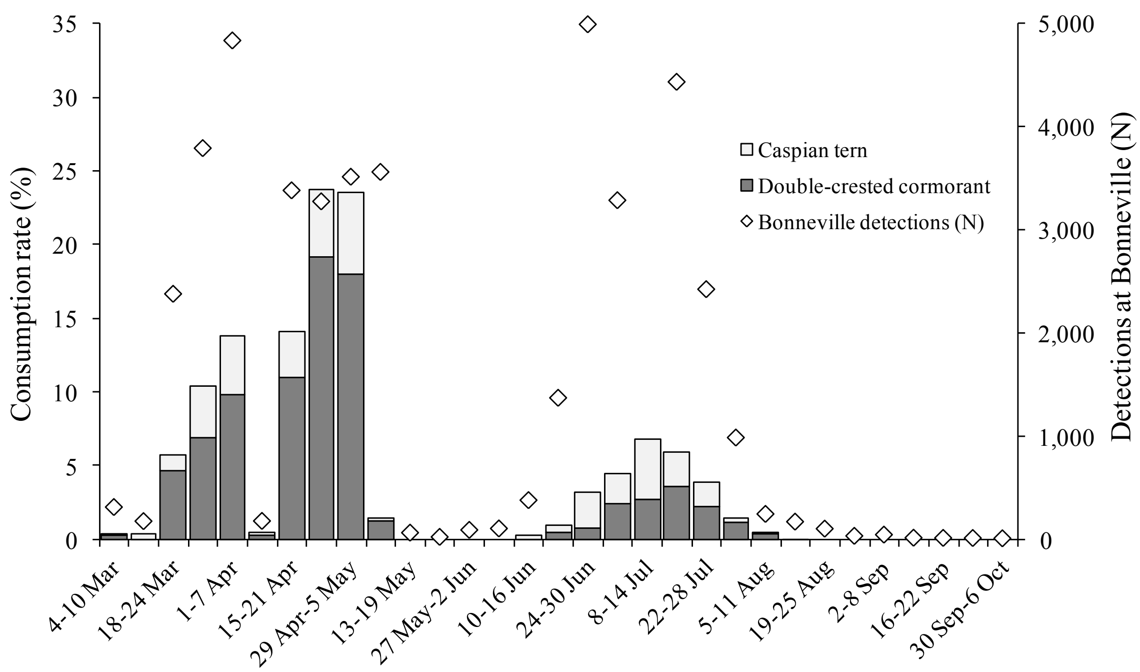

Figure 7. Seasonal predation rates by Caspian terns and Double-crested cormorants in the Columbia River estuary of PIT-tagged subyearling Chinook salmon by date of detection at Bonneville Dam. Predation rates were calculated for weeks in which a minimum of 100 fish were detected.

Comparative Predation of PIT-Tagged vs. PIT and Acoustic-Tagged Fish

A total of 36,436 double-tagged Chinook salmon were released into the CRB during 2008 (PTAGIS 2008). Sufficient numbers of double-tagged and PIT-tagged fish were released at or detected passing both Lower Granite and Bonneville Dam for comparisons of predation by tag type at both the mid-Columbia and estuary regions. The difference in mean travel time from Lower Granite to McNary Dam, a distance of approximately 401 km, was no more than 48 h for PIT-tagged and double-tagged yearling Chinook salmon (Table 11). Similarly, the difference in mean travel time of Chinook salmon from Bonneville Dam to the PIT-trawl (rkm 75), a distance of approximately 249 km, was no more than 24 h.

Table 11. Mean travel time in days and number of PIT-tagged and double-tagged (PIT and acoustic) fish detected passing at upstream and downstream detection locations within Mid-Columbia and estuary regions, 2008.

		Travel time (day)	
Species/Run	Release to detection location	PIT only	Double-tagged (PIT + acoustic)
Yearling Chinook salmon	Lower Granite to McNary Dam	13.8 (N = 520)	12.6 (N = 603)
Unknown Chinook salmon	Bonneville Dam to PIT trawl	1.7 (N = 237)	2.5 (N = 36)

Daily predation rates by terns and cormorants nesting in the Columbia estuary suggest that double-tagged fish were significantly more vulnerable to avian predation than their PIT-tagged counterparts. Mean predation rates for yearling Chinook salmon were 5.0% for double-tagged and 3.6% for PIT-tagged groups, and the difference was significant ($P = 0.016$; Figure 8). For subyearling Chinook salmon, overall mean predation rates were 4.5% for double-tagged and 2.6% for PIT-tagged fish (Figure 9), and predation rates of double-tagged subyearling Chinook salmon were also significantly greater than those of PIT-tagged fish ($P < 0.001$). For steelhead, mean predation rates were 15.6% for double-tagged fish and 13.3% for PIT-tagged fish (Figure 10). Unlike Chinook salmon, predation rates of double-tagged steelhead were not significantly different than those of PIT-tagged steelhead ($P = 0.194$). There were no clear temporal trends in predation rates between double-tagged and PIT-tagged fish of any species.

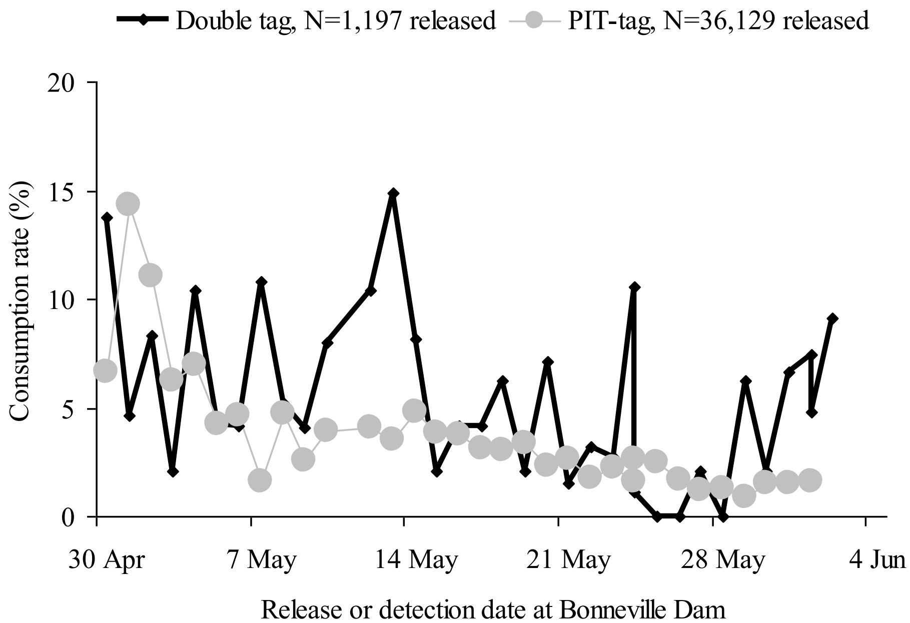

Figure 8. Daily mean predation rate on East Sand Island of double-tagged (N = 3,864) and PIT-tagged (N = 42,738) yearling Chinook salmon detected or released at Bonneville Dam during 2008. Overall means were 5.4% for double-tagged and 3.6% for PIT-tagged fish.

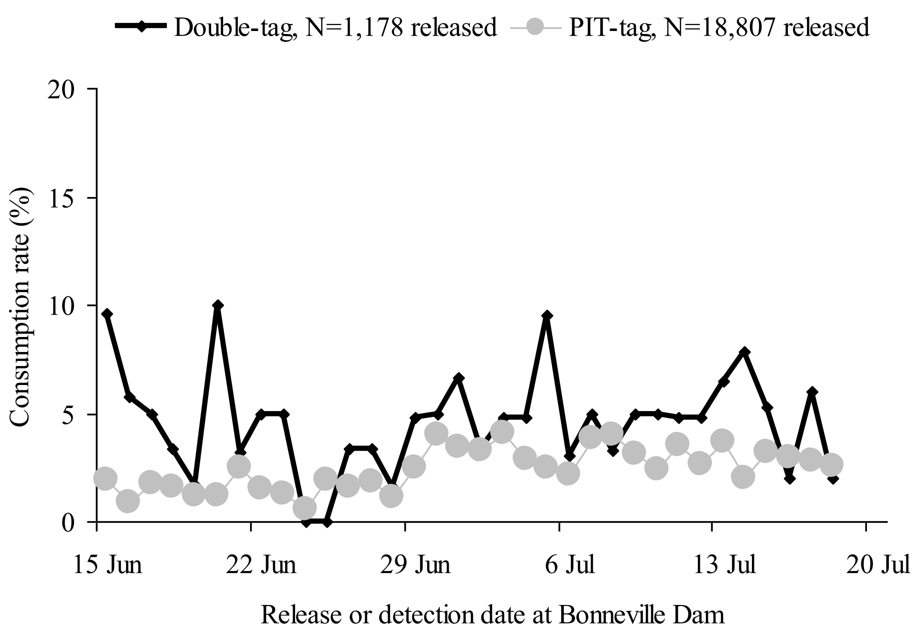

Figure 9. Daily mean predation rate on East Sand Island of double-tagged (N = 1,178) and PIT-tagged (N = 18,807) subyearling Chinook salmon detected or released at Bonneville Dam during 2008. Overall means were 4.5% for double-tagged and 2.6% for PIT-tagged fish.

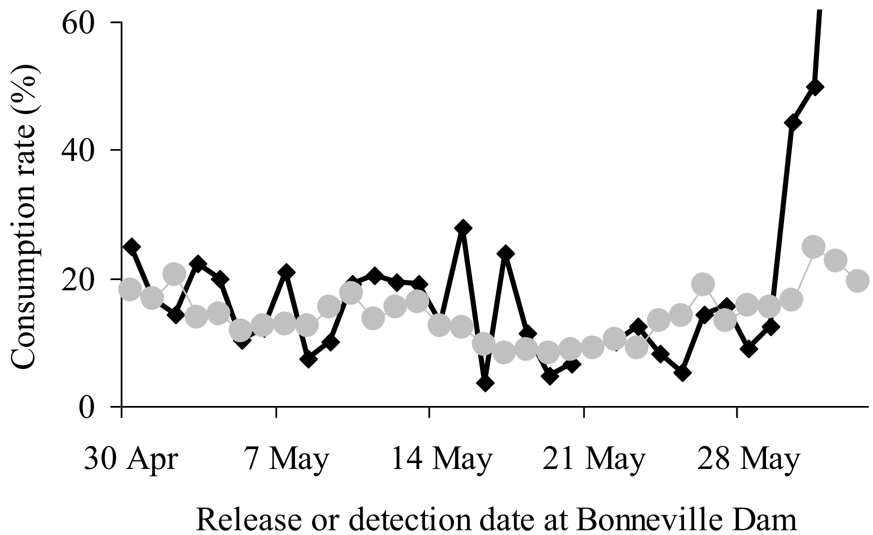

Figure 10. Weekly mean predation rate on East Sand Island of double-tagged (N = 754) and PIT-tagged (N = 26,502) steelhead detected or released at Bonneville Dam during 2008. Overall means were 15.6% for double-tagged and 13.3% for PIT-tagged fish.

We pooled into weekly intervals the predation rates of double-tagged fish and PIT-tagged fish found on Crescent and Foundation Islands and similar groupings for fish detected or released at Bonneville Dam and found preyed upon on East Sand Island (Figure 11). When pooled by week predation rates were greater for double-tagged Chinook salmon than for PIT-tagged fish on Crescent and Foundation Islands, but not statistically different ($P = 0.08$), with means of 1.6 and 0.6%, respectively. These predation rates were lower than those observed for Chinook salmon further downstream in the Columbia estuary. Mean predation rates in the estuary were 5.3% and 4.6 %, respectively ($P = 0.77$) and also were not statistically significant.

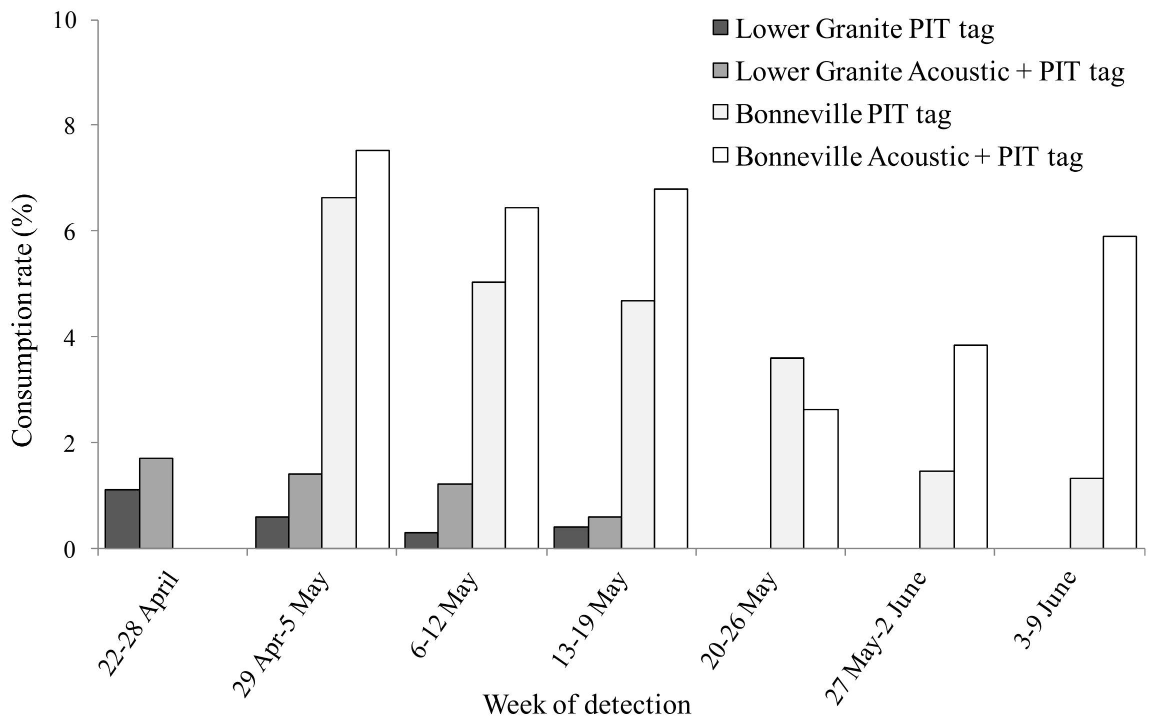

Figure 11. Avian predation rates of PIT-tagged and double-tagged Chinook salmon released from or detected at Lower Granite Dam and recovered on Crescent Island or Foundation Island. Also listed are avian predation rates of PIT-tagged and double-tagged Chinook salmon detected at Bonneville Dam and recovered on East Sand Island, 2008.

DISCUSSION

Since 1998, NMFS has provided PIT-tag recovery data for annual assessments of relative vulnerability to avian predators for juvenile salmonids throughout the CRB (Ryan et al. 2001, 2002, 2003, 2007; Glabek et al. 2003; Sebring et al. 2009). We continue to present a summary of basin-wide avian predation and report any relevant changes from the previous year, while focusing PIT-tag recovery efforts on specific avian colonies with potential management implications. In 2008, these colonies were the primary PIT-tag detection sites on islands in the Columbia River estuary and in the reservoir of McNary Dam. Annual collation of deposited PIT tags on these colonies provides an index to help determine the success or failure of management strategies for reducing impacts of avian predators on juvenile salmonids in the CRB.

Management actions became possible after approval of environmental impact statements (EIS) provided by the U.S. Army Corps of Engineers (USACE 2001, 2007, and 2008). Evidence upon which to base management decisions is now available from these EIS evaluations, previous studies of avian predation (Ryan et al. 2001, 2002, 2006, 2007), and the successful relocation of the tern colony from Rice to East Sand Island. Based on these data, the action agencies recommended relocation of Caspian terns to Fern Lake Ridge Reservoir, Crump Lake, and Summer Lake in southern Oregon and to several sites within San Francisco Bay (USFWS 2006). If successful, these relocations could reduce the number of terns nesting on East Sand Island and possibly Crescent Island, thereby further reducing impacts on juvenile salmonids and aiding basin-wide recovery efforts of ESA-listed stocks (USFWS 2006).

Our recovery of control tags placed on avian breeding colonies in 2008 yielded detection efficiency estimates consistent with those measured in 2007. Thus our efforts to reduce collision of tag codes on avian breeding colonies with large densities of PIT tags using shielding and a modified coil design were successful. Detection efficiency measurements for the cormorant colonies on East Sand and Foundation Island in particular were the greatest reported in several years since introduction of the SST tag and subsequent increase in tag-code collisions in areas of high PIT-tag density.

By tagging 12,000 hatchery subyearling Chinook salmon (tule stock) in the LCR, a reach where relatively few fish are PIT-tagged, we provided valuable data on the effects of avian predators to locally released fish stocks. Of the LCR subyearling Chinook salmon consumed, a consistently greater proportion was preyed upon by cormorants than terns. These data may indicate that vulnerability of LCR subyearling Chinook salmon is greater than that of any other ESU in the CRB.

As in previous years, our results indicated that for subyearling Chinook salmon, predation rates for LCR stocks were much greater than those for upriver bright stocks originating upstream from Bonneville Dam (Ryan et al. 2006). We found that for subyearling Chinook salmon migrating through the estuary during the same period, stocks originating in the LCR were at least five times more likely to be consumed by avian predators than those originating upstream from Bonneville Dam. The one exception was for subyearling Chinook salmon originating at Spring Creek National Fish Hatchery. High avian predation rates were observed for Spring Creek Hatchery subyearlings that were detected at Bonneville Dam during the early portion of the migration season. Predation rates on these fish were similar to those of subyearlings released in the LCR, likely because of the extended estuary rearing period of LCR subyearlings prior to migrating to the ocean (Teel et al. 2009).

Although both LCR and upriver bright stocks of PIT-tagged subyearling Chinook salmon were detected at Bonneville Dam, different migration and residence timing in the estuary may result in different vulnerabilities to avian predators. This was the first year that large numbers of PIT-tagged LCR subyearling Chinook were released upstream from Bonneville Dam. Similar releases of these fish are scheduled annually through 2010, and these releases will provide an opportunity for further comparison of predation rates between subyearlings detected at Bonneville Dam and those released in the LCR. Lower Columbia River subyearling Chinook salmon has shown an acute vulnerability to avian predators on East Sand Island, and to Double-crested cormorants in particular. Because of their high vulnerability to avian predation, these stocks can provide an effective indicator of success in evaluating abatement actions intended to protect threatened and endangered salmonid populations.

During the early 2000s, adult fall Chinook salmon catches in Oregon coastal waters and Columbia River inland waters were estimated at 41% of the annual North American catch and are valued at 22 million dollars (Mann et. al 2005). Though management decisions frequently focus on threatened salmonid stocks in the upper Columbia and Snake River Basins, it is also important to consider lower river stocks that are acutely vulnerable to avian predation. Management action to relocate avian colonies outside the estuary may benefit all salmonid migrants in the CRB.

The use of surgically implanted acoustic tags as a method to investigate spatially explicit migration behavior of juvenile fish has increased in recent years. This increase has led to greater scrutiny of the effects of acoustic tags on fish behavior (Adams et al. 1998b; Martinelli et al. 1998; Hockersmith et al. 2003) and survival (Lacroix et al. 2004; Hall et al. 2009; Wargo-Rub et al. 2009), either from the presence of tags or associated implantation procedures. Research comparing tag effects on yearling and subyearling

Chinook salmon implanted with acoustic and PIT vs. PIT tags only had smaller sample sizes than those used in our comparison, and these studies were not designed to examine differences related specifically to avian predation (Michelle Rub, NOAA Fisheries, personal communication).

Although more than 36,000 fish were implanted both with acoustic and PIT tags in 2008, variations in release location, type of acoustic transmitter, and date of release precluded a direct evaluation of the relative vulnerability of double-tagged vs. PIT-tagged fish to avian predators. However, for three species of Pacific salmon, we were able to develop an index of predation rates by tag type using groups of fish released or detected at the same time in locations proximate to avian colonies.

Comparisons of PIT tags detected on East Sand Island from these index groups were used to examine daily avian predation rates of double-tagged vs. PIT-tagged fish throughout the migration season. These comparisons included large sample numbers, which permitted the statistical power necessary to resolve subtle differences in predation rates. Similar analysis using index numbers of fish detected or released at Lower Granite and Bonneville Dam on a weekly basis did not reveal significant differences. This result was due to smaller sample numbers of both groups, which resulted in weaker statistical power.

Overall, avian predation rates of double-tagged yearling and subyearling Chinook salmon were nearly twice that of the PIT-tagged only fish. We found no difference in temporal predation rates between double-tagged and PIT-tagged fish. Further paired comparisons of PIT-tagged vs. double-tagged fish at various locations in the CRB throughout the migration season are necessary to more conclusively state the effect of double-tagging fish on vulnerability to avian predators.

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APPENDIX

Detection Data

Appendix Table 1. Number of control PIT tags planted on East Sand Island avian colonies by time and plot. Number of PIT tags detected and those planted are listed next to the percent detected by release plot.

Plant date		Caspian Tern			Double-crested Cormorant			Gull		
(2008)	Release details	detected	planted	%	detected	planted	%	detected	planted	%
5 Apr	pre-season							29	100	29
	pre-season colony wide	86	100	86	108	200	54			
	pre-season plots	94	100	94						
	pre-season south platform				75	100	75			
	pre-season trench				80	100	80			
	pre-season north platform				87	100	87			
28 May	mid-season plot	87	100	87						
16 Jul	mid-season plot	91	100	91						
18 Aug	post-season trench				99	100	99			
	post-season plot	98	100	98						
	post-season colony wide	100	100	100	168	200	84			
	post-season north platform				87	100	87			
	post-season south platform				95	100	95			

Appendix Table 2. Numbers of control PIT tags planted on avian colonies located in the middle and upper Columbia River by time and plot, 2008. Number of PIT tags detected and those planted are listed next to the percent detected by plot.

	Date planted		American white pelican			Caspian tern			Double-crested cormorant			Gull species		
Recovery site	(2008)	Details	detected	planted	%	detected	planted	%	detected	planted	%	detected	planted	%
Badger Island	13 Mar	pre-season	62	100	62									
	15 Oct	post-season	74	100	74									
Banks Lake	1 Apr	pre-season				2	50	4						
	2 Aug	post-season				50	50	100						
Crescent Isl	21 Mar	pre-season plot 1				24	100	24				53	100	53
		pre-season plot 2				37	100	37						
	25 Mar	pre-season												
	20 May	mid-season A plot 1				60	100	60						
		mid-season A plot 2				51	100	51						
	23 Jun	mid-season B plot 1				64	100	64						
		mid-season B plot 2				61	100	61						
	25 Jul	post-season												
		post-season plot 1				99	100	99						
		post-season plot 2				98	100	98				94	100	94
Foundation Isl	14 Mar	pre-season							77	100	77			
	2 May	mid-season A							71	100	71			
	7 Jun	mid-season B							81	100	81			
	25 Jul	post-season							68	100	68			
Miller Rocks Isl	20 Mar	pre-season												
		upper/lower										81	100	81
	19 Jul	post-season												
		upper/lower										84	100	84
Potholes Res	5 Apr	pre-season				33	100	33						
	22 May	mid-season A				71	100	71						
	24 Jun	mid-season B				78	100	78						
	19 Jul	post-season				72	100	72						
Rock Island	20 Mar	pre-season				43	50	86						
	7/19	post-season				50	50	100						

Appendix Table 3. Actual and estimated percentages of migration year 2008 in-river migrating PIT-tagged salmonids recovered from the Double-crested cormorant colony located on Foundation Island. Numbers of PIT tags recovered (n) predation rates are separated by ESU and only presented for species with more than 300 fish released.

		ESU								
		Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spring/Summer Chinook salmon	Hatchery	426	0.44	**0.59**	40	0.11	**0.14**	1,185	0.36	**0.48**
	Unknown	128	1.44	**1.95**	0	0.00		0		
	Wild	5	0.05	**0.07**	22	0.08	**0.10**	63	0.08	**0.11**
Fall Chinook salmon	Hatchery	236	0.19	**0.26**	13	0.43	**0.59**	798	0.12	**0.16**
	Unknown							25	0.56	**0.75**
	Wild	3	0.26	**0.36**	223	1.34	**1.81**			
Unknown Chinook salmon	Hatchery							995	0.75	**1.02**
	Unknown				3	0.05	**0.07**			
	Wild							56	0.26	**0.36**
Coho salmon	Hatchery	27	0.05	**0.07**	14	0.05	**0.06**			
Steelhead	Hatchery	758	2.62	**3.55**	50	0.10	**0.13**	1,598	0.62	**0.83**
	Unknown	2	0.05	**0.07**	2	0.04	**0.05**	81	2.21	**2.99**
	Wild	106	0.57	**0.77**	2	0.02	**0.02**	332	0.65	**0.88**
Sockeye salmon	Hatchery							16	0.32	**0.44**
	Wild							2	0.21	**0.29**

Appendix Table 4. Actual and estimated percentages of migration year 2008 in-river migrating PIT-tagged salmonids recovered from the Caspian tern colony located on Crescent Island. Numbers of PIT tags recovered (n) and predation rates are separated by ESU and only presented for species with more than 300 fish released.

		ESU								
		Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spring/Summer Chinook salmon	Hatchery	97	0.10	**0.16**	25	0.07	**0.11**	500	0.15	**0.24**
	Unknown	31	0.35	**0.56**						
	Wild	4	0.04	**0.06**	9	0.03	**0.05**	60	0.08	**0.12**
Fall Chinook salmon	Hatchery	158	0.13	**0.20**	10	0.33	**0.54**	2,664	0.41	**0.66**
	Unknown	6	0.07	**0.11**				81	1.80	**2.91**
	Wild	2	0.18	**0.28**	13	0.08	**0.13**			
Unknown Chinook salmon	Hatchery				247	0.19	**0.30**			
	Unknown							10	0.18	**0.29**
	Wild				86	0.41	**0.65**			
Coho Salmon	Hatchery	128	0.24	**0.38**				130	0.44	**0.70**
Steelhead	Hatchery	193	0.67	**1.08**	275	0.55	**0.88**	1,499	0.58	**0.93**
	Unknown		0.00	**0.00**	38	0.77	**1.24**	108	2.95	**4.76**
	Wild	53	0.38	**0.62**	24	0.20	**0.32**	691	0.91	**1.47**
Sockeye Salmon	Hatchery							13	0.26	**0.42**
	Wild				1	0.02	**0.03**	3	0.32	**0.51**

Appendix Table 5. Actual and estimated percentages of migration year 2008 in-river migrating PIT-tagged salmonids recovered from the Gull spp. and mixed colonies located on Miller Rocks Island. Numbers of PIT tags recovered (n) and predation rates are separated by ESU and only presented for species with more than 300 fish released.

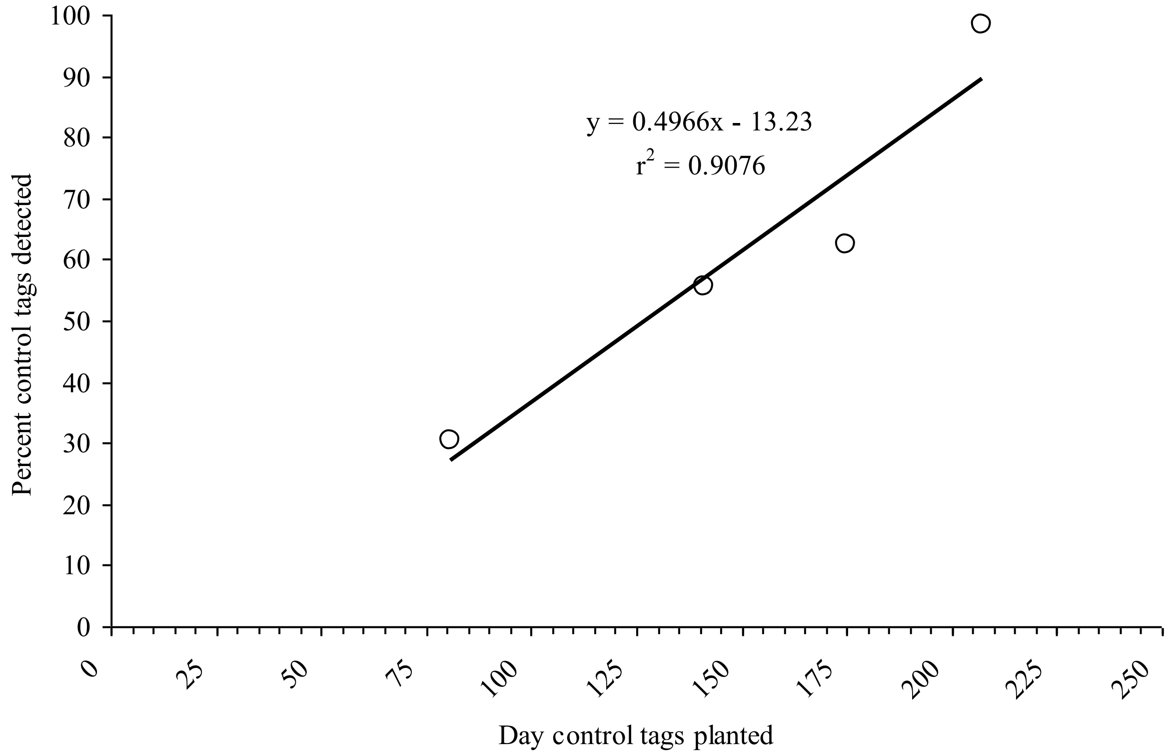
		ESU								
		Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spring/Summer Chinook salmon	Hatchery	74	0.08	**0.09**	42	0.11	**0.14**	346	0.10	**0.13**
	Unknown	21	0.24	**0.29**						
	Wild	11	0.11	**0.13**	23	0.08	**0.10**	22	0.03	**0.03**
Fall Chinook salmon	Hatchery	68	0.05	**0.07**	4	0.13	**0.16**	720	0.11	**0.13**
	Unknown	25	0.28	**0.34**				5	0.11	**0.14**
	Wild				12	0.07	**0.09**			
Unknown Chinook salmon	Hatchery							302	0.23	**0.28**
	Unknown				9	0.16	**0.20**			
	Wild							26	0.12	**0.15**
Coho salmon	Hatchery	40	0.07	**0.09**	80	0.27	**0.33**			
Steelhead	Hatchery	117	0.41	**0.49**	168	0.33	**0.41**	907	0.56	**0.68**
	Unknown	43	1.17	**1.42**	28	0.57	**0.69**	37	1.01	**1.23**
	Wild	56	0.32	**0.39**	18	0.15	**0.18**	180	0.36	**0.43**
Sockeye salmon	Hatchery									
	Wild							13	0.26	**0.32**

Appendix Table 6. Actual and estimated percentages of migration year 2008 in-river migrating PIT-tagged salmonids recovered from the Double-crested cormorant colony located on East Sand Island. Numbers of PIT tags recovered (n) and predation rates are separated by ESU and only presented for species with more than 300 fish released.

		ESU											
		Lower Columbia River			Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spring/Summer Chinook salmon	Hatchery	22	0.46	**0.81**	748	0.79	**1.39**	176	0.47	**0.82**	2,177	0.51	**0.90**
	Unknown				52	0.60	**1.05**						
	Wild	20	0.11	**0.20**	57	0.56	**0.99**	70	0.25	**0.43**	141	0.19	**0.33**
Subyearling Chinook salmon	Hatchery	2,891	22.29	**39.11**	3,037	2.43	**4.26**	16	0.53	**0.94**	2,721	0.42	**0.73**
	Unknown		12.79		100	1.12	**1.97**				6	0.13	**0.23**
	Wild				2	0.18	**0.31**	27	0.16	**0.28**			
Unknown Chinook salmon	Hatchery				108	1.53	**2.69**				1,130	0.65	**1.14**
	Unknown				56	1.14	**2.01**	25	0.46	**0.80**	30	0.24	**0.43**
	Wild	24	0.26	**0.45**							383	0.88	**1.55**
Coho salmon	Hatchery	152	7.20	**12.64**	109	0.34	**0.59**	145	0.49	**0.85**			
	Hatchery	96	2.72	**4.77**	463	1.21	**2.12**	390	0.78	**1.36**	4,393	1.70	**2.98**
Steelhead	Unknown			**0.81**	104	2.83	**4.96**	20	0.40	**0.71**	31	0.84	**1.48**
	Wild				208	1.16	**2.03**	72	0.60	**1.06**	863	1.13	**1.99**
Sockeye salmon	Hatchery										21	0.42	**0.74**
	Wild							29	0.57	**1.00**	6	0.63	**1.11**

Appendix Table 7. Actual and estimated percentages of migration year 2008 in-river migrating PIT-tagged salmonids recovered from the Caspian tern colony located on East Sand Island. Numbers of PIT tags recovered (n) and predation rates are separated by ESU and only presented for species with more than 300 fish released.

		ESU											
		Lower Columbia River			Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spring/Summer Chinook salmon	Hatchery	85	1.79	**1.92**	1,364	1.44	**1.55**	235	0.63	**0.67**	4,632	1.09	**1.17**
	Unknown				94	1.08	**1.16**		0.00	**0.00**			
	Wild	29	0.16	**0.18**	71	0.70	**0.75**	35	0.12	**0.13**	138	0.18	**0.20**
Subyearling Chinook salmon	Hatchery	504	3.89	**4.18**	933	0.75	**0.80**	17	0.57	**0.61**	2,594	0.40	**0.43**
	Unknown				117	1.31	**1.41**				5	0.11	**0.12**
	Wild				5	0.44	**0.47**	23	0.14	**0.15**			
Unknown Chinook salmon	Hatchery				157	2.23	**2.40**				2,418	1.39	**1.49**
	Unknown				54	1.10	**1.19**	19	0.35	**0.37**			
	Wild	32	0.34	**0.37**	2	0.84	**0.90**				416	0.96	**1.03**
Coho salmon	Hatchery	18	0.85	**0.92**	319	0.98	**1.06**	365	1.22	**1.32**			
Steelhead	Hatchery	355	10.06	**10.82**	1,428	3.73	**4.01**	2,425	4.83	**5.19**	17,799	6.88	**7.40**
	Unknown				339	9.21	**9.91**	171	3.45	**3.71**	143	3.89	**4.19**
	Wild				704	3.91	**4.20**	187	1.56	**1.68**	3,492	4.59	**4.94**
Sockeye salmon	Hatchery										16	0.32	**0.35**
	Wild							14	0.28	**0.30**	3	0.32	**0.34**



Appendix Figure 1. Percent of PIT tags from four release groups (pre-season, early mid-season, late mid-season, and post-season (n = 400) detected on the Crescent Island Caspian tern colony during 2008 that were intentionally scattered in different test plots. The regression equation was used to estimate a temporal change in detection efficiency on this colony.